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THE POTENTIAL FOR CAST BLASTING IN CANADIAN SURFACE MINES

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October 1986

This document was produced by scanning the original publication.

Ce document est le produit d'une numérisation par balayage de la publication originale.

(CANMET)

Énergie (CANMET)

21 pp

MICROMEDIA

MINERAL AND ENERGY
RESEARCH PROGRAM
COAL RESEARCH LABORATORIES
DIVISIONAL REPORT M & ERP/CRL 86-110(TR)

THE POTENTIAL FOR CAST BLASTING IN CANADIAN SURFACE MINES

by

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ABSTRACT

The use of explosives to cast overburden has increased rapidly during the 1980's. Several coal mines and quarries worldwide utilize blast casting to mine higher strip ratio pits or to improve the economics of mining existing pits. It is visualized that blast casting methods have the potential for successful application in some Canadian coal mines. This paper reviews the existing global technology in this field and identifies the situations where its use in Canadian mines could contribute to lowering the overall cost of overburden handling.

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LE POTENTIEL DE L'ABATTAGE À L'EXPLOSIF DANS LES MINES À CIEL OUVERT AU CANADA

par

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et

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RÉSUMÉ

L'utilisation des explosifs pour se débarrasser du mort-terrain a progressé rapidement durant les années 80. De nombreuses mines et carrières à travers le monde utilisent l'abattage à l'explosif pour augmenter leur taux d'extraction ou pour améliorer la santé économique des exploitations existantes. Il est donc envisageable que ces méthodes d'abattage à l'explosif aient le potentiel pour être appliquées avec succès dans quelques mines de charbon canadiennes. Le présent article revoit l'ensemble de la technologie en usage dans ce domaine et identifie les situations où cette pratique pourrait contribuer à abaisser les coûts inérants à la manipulation des morts-terrains dans les mines canadiennes.

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INTRODUCTION

Canadian coal production has increased dramatically over the past decade or so, from 21 million tonnes in 1974 to about 61 million tonnes in 1985. Currently, about two-thirds of annual production is thermal coal, most of which is used for domestic power generation. The remainder is metallurgical coal, the bulk of which is exported overseas mainly to Pacific rim consumers such as Japan and Korea for use in steelmaking.

Surface mining accounts for 95% of all Canadian coal production, with a large proportion of this production coming from the three western provinces of Saskatchewan, Alberta and British Columbia. The principal methods of surface mining in these provinces are strip and open-pit. Strip mining operations are found on the prairies of Saskatchewan as well as in eastern and central Alberta, where the seams are generally flat and are overlain by glacial till. This overburden is usually removed by large draglines without prior blasting. The open-pit mining operations are found in the Rocky Mountain regions of western Alberta and eastern British Columbia. In this area, tectonic disturbances have served to fault and fold the coal seams, making them irregular and somewhat localized. Rock types range from very weak shales and mudstones to very hard and massive sandstones. For the most part, the rock must be blasted and is then removed either by truck and shovel methods or in some cases by draglines.

One of the largest problems facing Canadian coal producers is geography. The western coal mines are quite distant from the large domestic thermal markets in the east, and are also some 1000 kilometres from tidewater ports on the west coast. Consequently, transportation costs are exceedingly high and producers must strive to minimize costs incurred at the minesite.

Currently, the average strip ratio for Canadian surface coal mines is about 4.5:1, meaning that 4.5 bank cubic metres of overburden must be removed in order to expose one tonne of coal. It follows then, that with the large amount of overburden to be handled, the key to improving the overall economics of a given operation, is to find more cost-effective ways of removing this overburden.

In recent years, many operations in the U.S.A., Australia, and South Africa have turned to blast casting as an extremely economical means of moving overburden. This technique utilizes explosive energy to fragment the rock mass and cast a large portion of it directly into previously worked-out pits or spoil piles. Therefore, it is not necessary to subsequently excavate this waste with stripping equipment and a cost-saving is incurred.

This paper reviews the technique of blast casting and examines potential applications of this technology to surface coal mines in Canada.

2 OVERVIEW OF BLAST CASTING TECHNOLOGY

Blast casting (also known as explosive casting or controlled trajectory blasting) is a technique whereby overburden is horizontally displaced by blasting, causing a portion of the material to be thrown into a previously mined-out cut. Various investigators have shown that up to 65% of the material in a particular blast can be cast in this manner, resulting in cost savings of up to 35%.

Successful casting of material will be a function of the following:

- Velocity of material leaving rock face
- Distance the material is cast
- Ability to cause displacement over full height of face
- Freedom of successive rows in a blast to displace horizontally
- Degree of fragmentation

2.1 Factors Affecting Blast Casting

Following, some of the factors which control the success of blast casting are discussed in general terms. Numerical values have been deliberately avoided in the text but design values recommended by various investigators have been summarized in Table 1.

Energy Factor

Powder factors expressed in kg/m^3 are not a useful design

criterion in blast casting. The reason for this is that the "ejection" velocity and lateral displacement of the burden rock are related to the weight rather than the volume of rock. Because the energy generated per unit weight of charge varies with the chemical composition of the explosive, one should use energy factors rather than powder factors as a blast design criterion. It is the amount of explosives' energy (not the weight of explosive) which controls the displacement of each tonne of rock.

Energy factors should not be used as the sole design criterion for blast casting. For example, two blasts with equal energy factors but with dissimilar charge distributions can give quite different displacements of the rock. The same can be said when comparing two blasts using ANFO which has high heave energy, versus a blast using a slurry explosive with high strain wave energy.

Explosive Type

The best blast casting results have been achieved with explosives that maximize the ratio of heave energy to strain energy. Explosives with a relatively high proportion of strain wave energy do not perform well in blast casting because such energy is rapidly and wastefully dissipated by pulverizing the rock in the vicinity of the blast hole wall.

ANFO has found successful application in blast casting due to its relatively high heave energy to strain wave energy ratio. As well, heavy ANFO blends, typically 35% emulsion, perform very well due to their high bulk strengths and good heave energy production.

Rock Properties

For a given amount of heave energy and a certain blast geometry, susceptibility of a rock mass to blast casting increases with a decrease in rock density and with an increase in Young's modulus (E). When rock types with low values of E are subjected to blasted-induced compressive stress, a comparatively high proportion of the explosion energy is transformed into potential energy as the rock undergoes elastic compression. This energy is

lost in terms of casting, since the subsequent release of compression does not contribute to the kinetic energy required for forward movement of the rock.

The nature, extent and directions of joints and bedding planes will contribute to the effectiveness of blast casting in a particular rock mass. When major discontinuities are at right angles to the free face, explosion gases have a greater opportunity to escape prematurely to the atmosphere. Where the major discontinuities are parallel, or sub-parallel to the free face there is more interaction between adjacent blast holes and blast casting is generally more effective.

Table 1. Design parameters for blast casting

Pit width to bench height ratio	- 1.0 - 1.3
Minimum bench height	- 12m
Blast hole diameter	- 170mm - 270mm
Blast hole inclination	- theoretically 45°
	- practically 15 - 20° or perpendicular to bedding
Burden to spacing ratio	- 0.7 - 1.0 where discontinuities normal to free face
	0.5 - 0.7 where discontinuities
Stemming	- greater than or equal to burden distance
Powder type	- ANFO, heavy ANFO, (explosives with a good heave energy to strain energy ratio)
Powder factor	- 0.5 - 0.9kg/m^3(see comments in text)
Energy factor (EF)	- typically 2-3 times EF for regular production blast
Pattern tie-in	- one free face: rows parallel to face
	two free faces: 30° angle to highwall
Timing of blast	- inter-row delays should be 6.5-10ms per metre of burden
Percentage of overburden successfully casted	- 30% - 60%

*It should be noted that values in this table do not reflect the authors' experience but were derived from a survey of work by other investigators.

Burden and Spacing

The ratio of burden to spacing in a blast casting pattern must be such that the explosion gases from each charge exert their forward push over the greatest possible area in the plane of the row of blast holes. The spacing, however, must not be so large that gases vent from the face before they fully penetrate the cracks between adjacent blast holes. This is especially a concern if a major set of discontinuities are at right-angles to the free face. Burden distance must be balanced so that for a given hole diameter and explosive type, the ejection velocity and fragmentation are maximized. When the burden carried by a charge is too large, little breakage or displacement occurs. When the burden distance is too little, the face will burst prematurely which results in loss of fragmentation and decreased ejection velocities.

Bench Height to Pit Width Ratio

The success of a cast blast in terms of the amount of material being cast, is related to the height of the highwall (H) and the width of the cut being blasted (W). It has been found by a number of investigators that as the H/W ratio increases, there is a proportional increase in the percentage of material successfully cast. Thus, the greater the height of the highwall, the lower the cost of moving overburden with explosives.

Blast Hole Inclination

Basic theory applied to the trajectory of missiles and other projectiles predicts that a blast hole inclination of 45° from the vertical will provide the maximum trajectory distance over a horizontal surface. In actual practice, however, such an angle is impractical to drill with large-diameter production drills. To date, the maximum angle which has been achieved in a production drilling situation is 19° with 10 5/8 inch (270 mm) diameter holes.

Initiation Sequence and Delay Timing

Unlike most conventional blasts, blast casting should employ a row-by-row initiation sequence. This sequence will ensure that:

- the principal direction of rock movement is normal to the free face and
- forward movement is not dimished by in-flight collisions between rock fragments.

When two free faces are available for blast casting, tie-ins at an oblique angle to the highwall have met with some success. It is important that all holes in a given row be fired simultaneously to ensure that shearing forces between holes do not limit the ejection velocity at the free face. Also, inter-row delays should be such that the burden of each row is effectively detached from the rock mass by the time the next row detonates. The best way to determine the optimum inter-row delay time for a given rock mass is by filming a number of blasts with a high-speed motion picture camera.

2.2 Review of Blast Casting Practices at Selected Properties.

In order to appreciate the potential problems in applying blast casting technology to Canadian coal mines, it will be helpful to briefly review a couple of operations where this technology has been used successfully.

2.2.1 Colowyo Coal

The Colowyo Mine, operated by the Colowyo Coal Co., is located in northern Colorado near the Wyoming border. This mine produces 3 million tonnes of coal per year from eight mineable seams which dip at 6 percent and range in thickness from 1m to 4m.

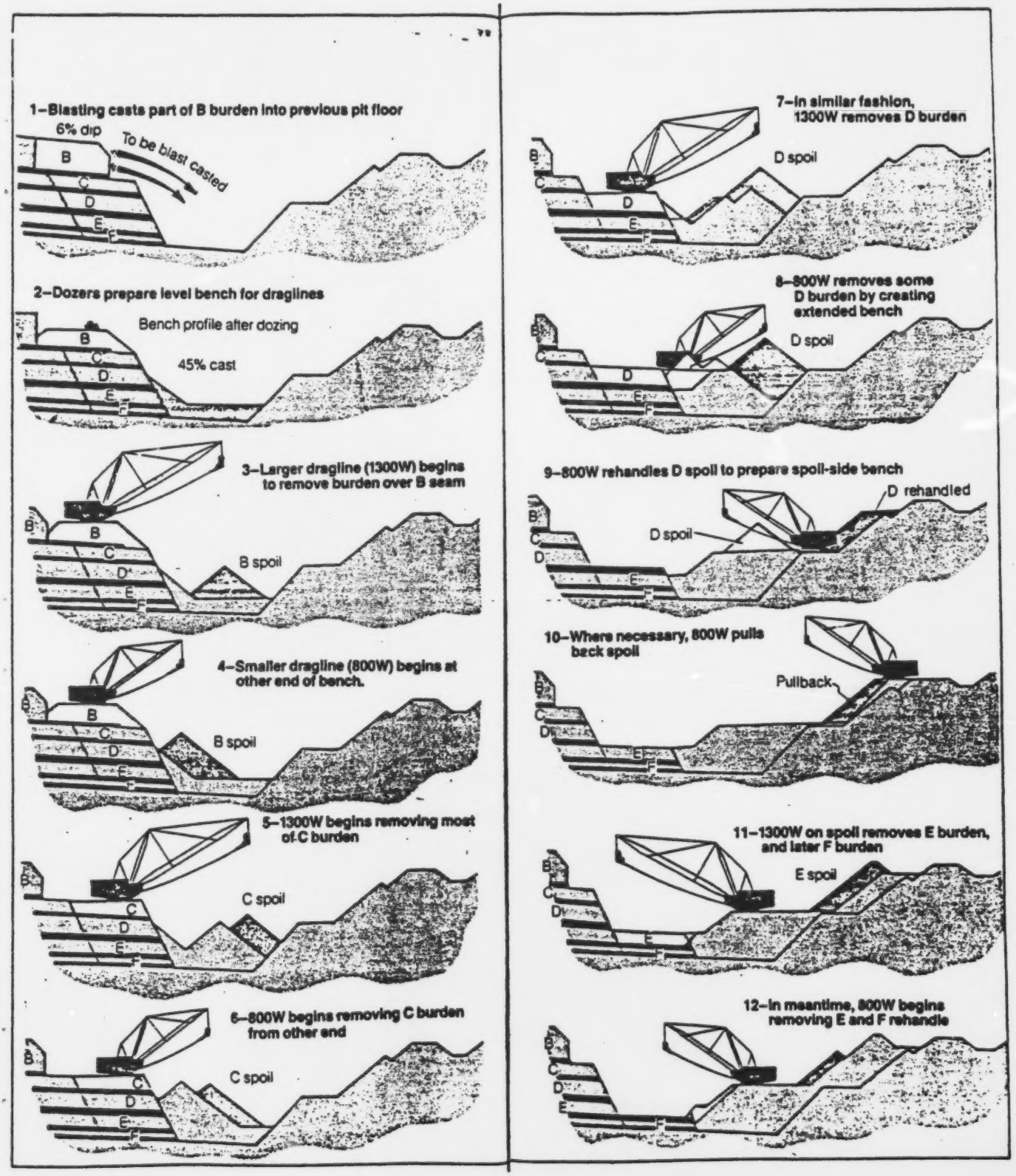

1–Blasting casts part of B burden into previous pit floor
6% dip
To be blast casted
B
C
D
E
F
2–Dozers prepare level bench for draglines
Bench profile after dozing
45% cast
3–Larger dragline (1300W) begins to remove burden over B seam
B spoil
4–Smaller dragline (800W) begins at other end of bench.
B spoil
5–1300W begins removing most of C burden
C spoil
6–800W begins removing C burden from other end
C spoil
7–In similar fashion, 1300W removes D burden
D spoil
8–800W removes some D burden by creating extended bench
D spoil
9–800W rehandles D spoil to prepare spoil-side bench
D rehandled
D spoil
10–Where necessary, 800W pulls back spoil
Pullback
11–1300W on spoil removes E burden, and later F burden
E spoil
12–In meantime, 800W begins removing E and F rehandle

Fig.1 Mining sequence at Colovyo coal mine (After Chironis, 1985)

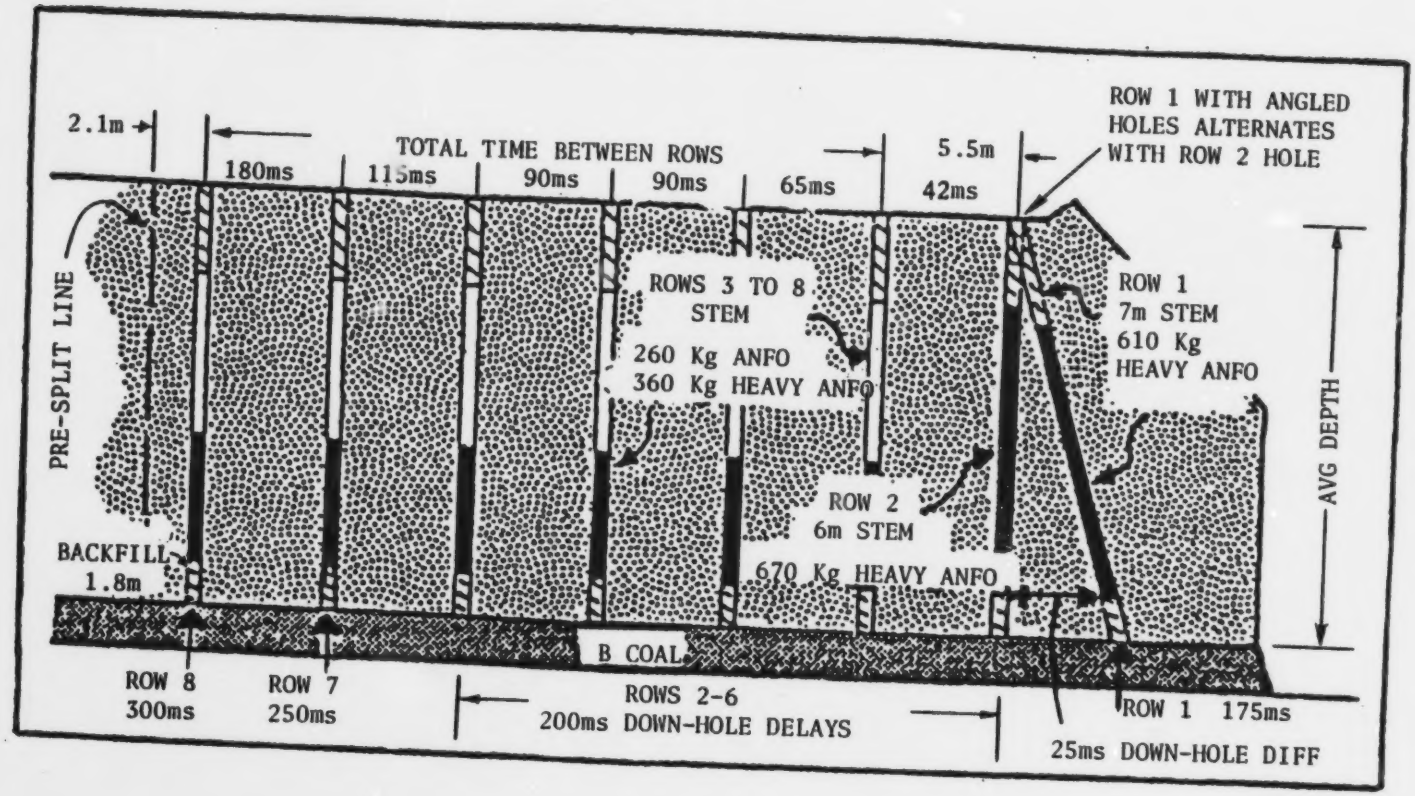


Fig.2 Typical hole pattern for blast casting at Colowyo coal mine (After Chironis, 1985)

The upper three seams at Colowyo are removed by conventional truck and shovel methods while the lower five seams are removed by dragline. As can be seen in Figure 1, blast casting is used above the first dragline seam (B seam) in order to prepare a bench for the dragline.

Figure 2 shows a typical hole pattern for blast casting at the Colowyo Mine. Blastholes are 250mm in diameter and are drilled on a staggered pattern with 5.5m burdens and 8m spacings. These holes are drilled to a depth that just touches the coal seams, then backfilled 2m. Average hole depth is 19m. In a typical casting shot at Colowyo there are eight rows of blast holes. The first row of holes is angled at 15 degrees, the remaining rows are vertical. The explosive types used are heavy ANFO and straight ANFO. The first two rows of the shot are loaded with heavy ANFO. Remaining holes are loaded with a toe-load of 24/76 heavy ANFO and a column load of straight ANFO.

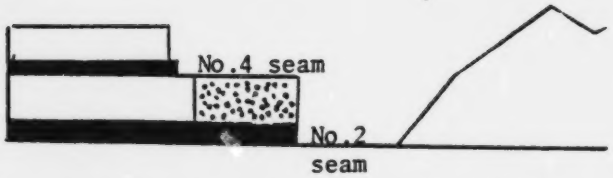
Colowyo has found that the timing between rows is important in getting a successful casting shot. Delay times range from 25ms between rows 1 and 2 to 180ms between rows 7 and 8. In order to avoid cut-offs, down-hole delays ranging from 175ms to 300ms are used in conjunction with surface delays.

Blast casting has proven to be a very efficient and economical way of preparing Colowyo's B-seam cut for dragline mining. Approximately 45% of the total material in this cut is currently being cast with substantial cost savings.

2.2.2 Rietspruit Coal Mine, South Africa

Rietspruit is a Rand Mines/Shell Mining joint venture located near Johannesburg, South Africa. This mine produces approximately 9 million raw tonnes of thermal coal annually from two major and two minor seams using a $53m^3$ dragline.

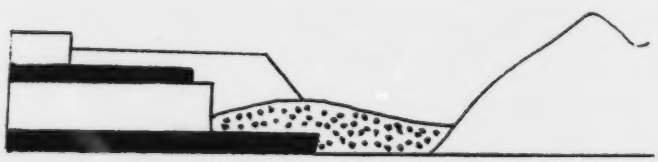
Blast casting is used in conjunction with the dragline to mine the two major seams as illustrated in Figure 3. Rietspruit uses pre-splitting to separate the block of material to be cast from the remainder of the rock mass. In this application a single row of holes, 250mm in diameter and 3m - 5m apart (depending on rock type) is drilled to the top of the coal seam along the line of the new highwall. Each pre-split hole is then lightly loaded with 50-60 kg. of ANFO and the charges are detonated simultaneously.



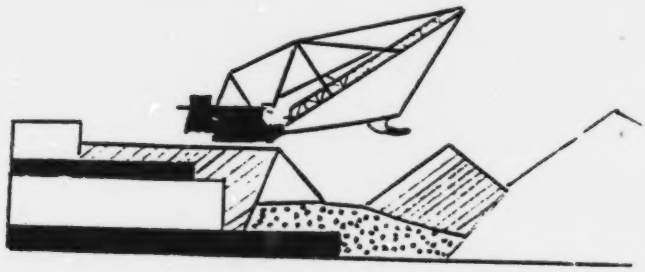
1. CONFIGURATION BEFORE START OF CYCLE

2. MIDBURDEN BLAST CASTED

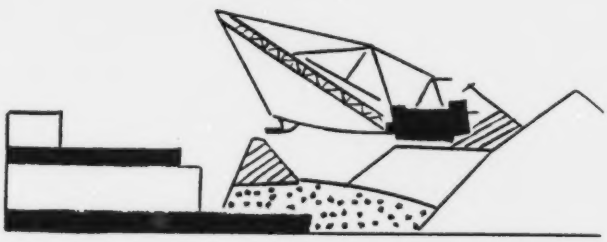
3. OVERBURDEN BLAST CASTED



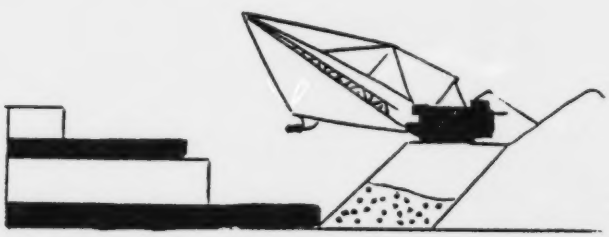
4. DOZER PAD PREPARATION



5. KEY CUT TO NO.2 SEAM AND DIAGONAL CHOP DOWN TO NO.4 SEAM. THIS MATERIAL IS USED TO BUILD THE IN-PIT BENCH



6. PULL BACK FROM IN-PIT BENCH



7. NO.2 SEAM EXPOSED

Fig.3 Mining sequence at Rietspruit coal mine (After McDonald, Smith and Crosby, 1982)

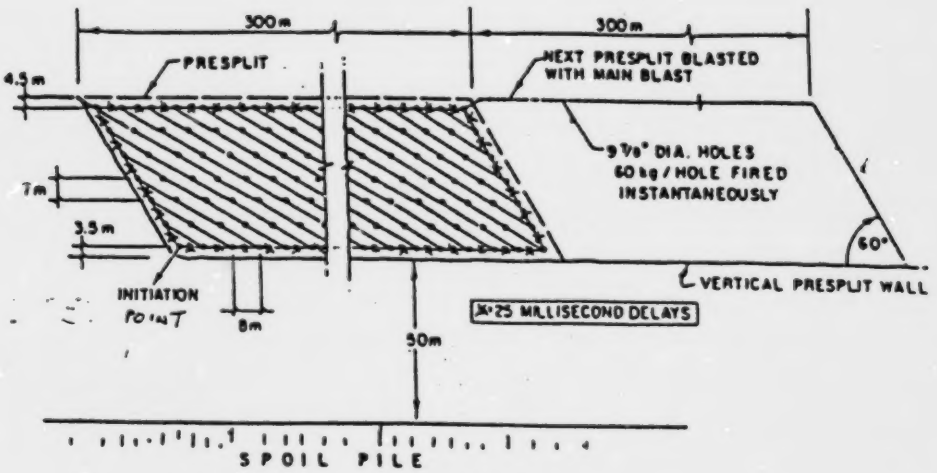


Fig. 4 Plan view of pre-split and main cast blast tie-in at Rietspruit

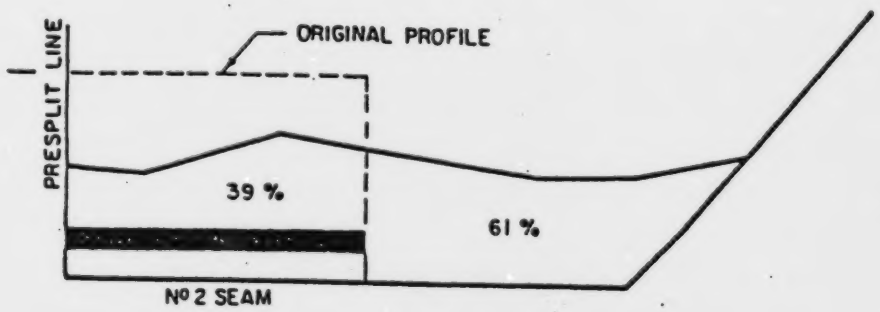


Fig. 5 Typical after blast profile on seam 2 at Rietspruit (After McDonald, Smith and Crosby, 1982).

As shown in Figure 4, the remaining holes in the blast are drilled on a staggered pattern with a 7m burden and 8m spacing. With two free faces, the holes are tied-in at a 30° angle to the highwall which makes the effective burden about 4m. These holes are loaded with ANFO and fired row by row with a 25ms delay between rows. Some of the advantages of blast casting at Rietspruit are:

(a) Previously, it required two passes of the dragline to expose the two seams whereas with blast casting, both seams can be exposed with one pass.

(b) Use of pre-splitting means less toe burden on crest holes of ensuing cast blast which results in better throw of the material.

(c) Up to 61% of seam 2 cut is cast meaning less volume to be handled with the dragline. (See Figure 5)

Both Rietspruit and Colowyo Coal have reported improved economics through the use of blast casting. Not only has this technique resulted in less material having to be moved by mechanical means, it has also improved loading equipment cycle times through enhanced fragmentation and looser muckpiles.

3 APPLICATION TO CANADIAN OPERATIONS

3.1 Rocky Mountain Coal Mines

Coal mines located in the Rocky Mountain region of British Columbia and Alberta generally use shovel and truck methods in order to strip overburden from coal seams that range from flat to steeply dipping (45°) in orientation. In some cases, draglines are employed to strip waste and lift coal in mountainous terrain.

Blast casting principles have good potential application for both truck/shovel and dragline methods in Rocky Mountain Coal mines. The suitability of blast casting is actually enhanced by the physical characteristics of the region. Applications include the following:

Phased Pit Sequences or Highwall Pushbacks

Where coal seams run flat or dip into a mountain or hillside, a subcrop or contour pit is usually developed. As the pit limit is moved into the hillside the strip ratio rapidly increases. In this type of operation, a combination truck/shovel - cast blast mining method should allow the economic mining of higher strip ratio coal and thereby increase mineable reserves. As well, a pit limit designed on truck/shovel economics can be mined using this method in order to improve the overall economics of the pit by lower overburden handling costs.

Basically, the approach involves the utilization of shovels and trucks to remove the lower or first contour cut of the pit. This cut is then pushed back by castblasting high wall slices down to mineable coal into the mined-out truck/shovel pit. Access must be maintained for cast blast drilling of the highwall. Depending on existing topography, this may require development access to upper cuts outside of the pit limits. Based upon the height of cut to width of cut ratio as much as 60 to 70% of a highwall slice can be cast into the mined-out truck/shovel cut, the remainder being dozed over.

This procedure eliminates the high cost components of loading and hauling waste. However, drilling and blasting costs should increase by approximately 30-50 percent. A cross section of a typical phased push back is illustrated in Figure 6.

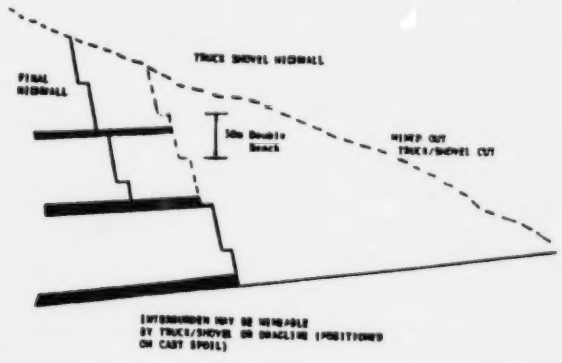


Fig. 6 Highwall pushback using cast blasting

Mountain-Top and Shovel Pits

Blast casting may be used when blasting to topography on mountain top mines or against ridges with steep flanks. The increased explosive energy is directed to throw overburden down-slope. Essentially the application reduces the truck/shovel pre-stripping required to develop a mountain-top operation. The cast material would likely be excavated as rehandle at a much later time, thus deferring loading and hauling costs.

Since this application involves blasting to original ground topo, toe burdens may be quite large, therefore angled holes (20°) should be used to allow good lateral displacement of the first row.

Fording Coal Limited has conducted some preliminary investigations in the area of mountain-top cast blasting. Four large test blasts, on a 15 metre bench cut and a 40 metre shot width, have been fired and evaluated in the Eagle Mountain mining area at the Fording River Operations. The tests have been very successful to date with volumes in the range of 30 to 40% of the shot much being cast downslope. In terms of economics, the percentage volume of waste that had to be cast in order to pay for the increased cost of drilling and blasting was approximately 15 percent.

Casting Hangingwall Waste off Steeply Dipping Seams

Steeply dipping seams (45°) pose a considerable problem in truck and shovel applications. When drilling and charging below steeply dipping coal, the lower explosive deck may be positioned quite close to the footwall of the coal seam.

Although coal shots are generally fired up dip, the proximity of the charge usually results in a heaved foot wall. Seam footwall clean up becomes more difficult and dilution increases dramatically.

Down dip casting of hanging wall waste using angled drilling has many advantages in steeply dipping seam operations. Blast holes are drilled to coal and charged above the hang wall of the seam in order to cast waste off the coal in the downdip direction. If the interburden between seams is large, vertical holes can also be employed thus increasing drill efficiencies.(See Figure 7)

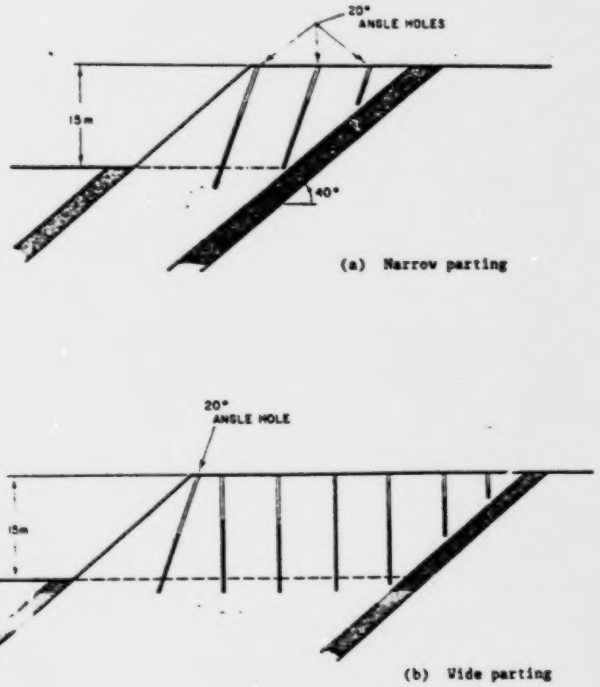


Fig. 7 Casting hanging wall waste off steeply dipping seams.

This method has the following advantages:

1. Improved muck pile diggability due to the higher energy factor employed to cast.
2. Shovel hangwall cleanup is reduced.
3. Difficult dozer push of hanging wall waste at top of seam is reduced or eliminated.
4. Shovel can clean coal to a hard unblasted footwall minimizing dilution.
5. Less dilution results in decreased rejects production and reduced coal haulage costs.

Dragline Applications

As outlined previously, there has been a great deal of experimentation on cast blasting in order to improve dragline productivity and reduce overburden handling in material that must be drilled and blasted. Casting overburden from flat dipping seams into exposed dragline cuts should find good application in Canadian Rocky Mountain Mines.

3.2 Prairie Coal Mines

The application of cast blasting to Canadian prairie coal mines is limited at best. Most prairie dragline mines do not blast overburden regularily. Overburden usually consists of glacial tills. In this environment, dragline total stripping costs are commonly less than the cost of the explosives required for cast blasting alone. As well, explosive casting energy losses are great in loose strata.

Some prairie strip mines occasionally encounter hard formations that require blasting. If these areas can be identified by exploration drilling in advance of production then cast blasting may be adapted into cut sequences.

4 CONCLUSIONS

Blast casting does have a potential for improving productivities in Canadian surface mines. Extensive field trials should be conducted in order to assess the feasibility and benefits of these applications and to provide a reliable technical data base upon which effective cast blasts can be derived.

CANMET and Fording Coal have initiated such a trial. In the next 9 months, full scale tests will be done at three different mining areas. The evaluation will include:

- high speed photography of each blast
- measurement of amount of O/B blasted
- comparison of actual versus predicted blast results
- assessment of effectiveness and consistency of each blast
- quantification of any problems encountered
- cost/benefit analysis of cast blasting versus conventional overburden handling.

REFERENCES

Bauer, A., J. L. Workman & W.A. Crosby 1983. "Principles and Applications of Displacing Overburden in Strip Mines bvy Explosives Casting." Presented at SME-AME Fall Meeting and Exhibit: Salt Lake City, Utah.

Chironis, N.P. 1984. "Angled Drilling Aids Casting." Coal Age, Volume 89, Number 1: pp. 64-67.

Chironis, N.P. 1985. "Blast Csting Succeeds at Multi-Seam Western Mine." Coal Age, Volume 90, Number 11: pp. 55-58.

Hagan, T.N. 1979. "Optimum Design Features of Controlled Trajectory Blasting (CTB)." Proceedings of the Fifth Conference on Explosives and Blasting Technique. Society of Explosive Engineers: St. Louis, Mo. pp. 21-28.

McDonald, K.L.' W.K. Smith & W.A. Crosby 1982. "Productivity Improvements for Dragline Operations Using Controlled Blasting in a Single and Multiple Seam Open Cast Coal Operation of Rietspruit, South Africa". Surface Mines, Volume II, Number 4. Bucyrus-Erie Company: South Milwaukee, Wisconsin, pp. 4-15.

EMR-Canmet Contract: Surface Mining Laboratory, Devon & Fording Coal Ltd. (Contract #23440-6-9022/01. "Demonstration and Evaluation of Blast Casting in a Producing Canadian Surface Coal Mine.

Naidu, H.G. & R.K. Singhal 1986. "Application of Blast Casting and Inclined Drilling". Canmet-CRL Internal Report.